FRACTIONALIZED CUBE MODULAR CONSTRUCTION SYSTEM

Cross-Reference To Related Applications

This application is a continuation-in-part of application Ser. No. 08/676,493, filed July 8, 1996, now abandoned, and continuation-in-part of application Ser. No. 09/002,807, filed January 5, 1998, now abandoned, and continuation-in-part of application Ser. No. 09/389,697 filed September 3, 1999.

Field of the Invention

This invention is related to the field of prefabricated, modular panel construction as applied primarily to architecture. It relates particularly to a method of construction by which a plurality of panels of various shapes and sizes can be assembled in ways that are capable of producing architectural spaces for a diversity of functional applications and aesthetic expressions. What distinguishes this invention from other related modular construction systems is the extent to which it is able to achieve the above objective in terms of complexity, variety, flexibility as well as efficiency and economy.

Background of the Invention

Prefabricated and modular panel construction is emerging in response to the high cost of conventional construction. This high cost results from the vast number of materials, weather factors and field labor time involved. One response to dealing with these factors has been to prefabricate all, or portions, of buildings to be shipped for placement or assembly on the site.

Mobile homes, houses built in two parts (side by sides), modules or sections for larger assemblages are examples of attempts to lower construction costs. Another method entails prefabricating most all the components of a given design in the factory, forming a kit of parts, to be assembled on the site. Log home kits, steel and pole building systems typify this approach. Both of these approaches are simply attempts at streamlining the production of buildings through standardization, assembly line fabrication methods and reducing field labor time. Far from being modular, these building systems essentially replicate conventional field construction, which, with the above-mentioned shortcuts, result in buildings that may be more cost effective, but typically repetitious and expressionless. Design latitude is sacrificed for construction economy, further hampered by transportation restrictions.

Truer to the idea of "modular", prefabricated construction, although less common, are building types based on forms like the sphere; i.e., geodesic dome, regular or semi-regular polyhedra such as the tetrahedron, octahedron and others. The disadvantage of using these forms as space enclosing envelopes for architectural applications is their total inability to be modified in manners of shape, proportions and volume to accommodate varying functional requirements. A given polyhedron can be repeated to form a larger aggregate, useful for bridges, space frame platforms, etc., but not enlarged or reduced to various proportional sizes and joined without customized transition linkages. In addition, the curvature of a geodesic dome, or the profusion of angled surfaces inherent in polyhedral forms, result in spaces that are difficult to subdivide and tend to yield many non-functional dead spaces.

Regardless, systems employing factory-made panels that can be assembled on site still offer the greatest potential for achieving low cost, functional, diverse and aesthetically interesting architecture. The greatest obstacles to achieving this potential in present art, however, appear to be two-fold. First is the tendency for proposed building systems to rely on or employ derivations of regular or semi-regular polyhedra or the sphere. Developing architecture based on these forms is inherently impeded by the limitations described above. The second obstacle is the issue of joinery. To achieve truly diverse and flexible design capabilities, the problem of connecting prefabricated architecture panels to each other or joining a multiplicity of panels in many and unpredictable combinations has not been successfully solved. The many systems described in prior art are all successful to a degree, but not capable of achieving the total flexibility and applicability sought by the present invention herein described.

The most common system in use today employs structural members, usually metal tubes called struts, joined at each end by a connector, called nodes, which link like struts converging from different angles together at a point, called the vertice. Together they form a structural framework to which panels are attached, usually to one side or the other of planes defined by strut perimeters. This feature alone automatically limits the number and configuration of panels that can be joined about any given node. However, an even greater obstacle to flexibility is the difficulty in designing a node capable of anchoring struts from very many angles. Beyond a limited number, less than 10, the node for connecting the struts becomes excessively massive and complicated. This is not only impractical, but unfeasible, for achieving the hundreds of strut angle

combinations required for successful realization of capabilities or objectives established by the proposed invention.

Another approach to the issue of panel joinery is edge splicing, where panels are joined continuously along their sides. This is applicable only for a few panels about any given axis that must also be impractically thin.

The approach which the present invention is most closely associated with is the common hinge. Hinges have been in use for centuries and their many variations and adaptations have accommodated many applications, including some architectural. The hinge consists essentially of two flanges with attached barrel loops on one side, each attached to a separate panel. The barrel loops of each flange, offset with respect to each other, are then aligned an axis between panels, through which a solid rod or pin is inserted effecting the joinery of the two panels. Several additional panels may also be added, requiring only a longer axis pin to pass through all the barrels. The problem with the application of the hinge, per se, is that it is always a pair designed for two panels; whether three, four or five panels are joined, the hinges function as pairs.

This implies the need for pre-planning each joint and careful alignment, as the barrel loops of each flange anticipate the position of its mate on the adjoining panel. As with edge splicing, problems with hinged connections become complicated with increasing panel thickness. Panels so joined are, as is the case with the present invention, rotational with respect to the axis about which they are joined; in themselves, there is no provision for fixing the angle between panels. This system must rely entirely on a configuration with other panels to fix a panel's orientation

within the assemblage. Also, hinges are designed expressly for use with panels. They are not envisioned or designed for struts that span between vertices. Neither does the application of hinges for panel joinery specifically address the vertice condition, important for achieving practical applications in architecture.

Therefore, in light of the preceding discussion and of current art, a comprehensive solution for the creation of architectural structures and spaces that are practical, flexible, and diverse in aesthetic expressions as well as technically and economically feasible, is viewed as still outstanding. It is this comprehensive solution which this invention, along with additional embodiments and advantages herein described, was conceived to address.

Summary of the Invention

There are two major aspects that constitute the embodiment of the present invention herein described. The first aspect involves a geometric derivation approach that provides a special selection of panel shapes and sizes. Related to each other through a common format, these shapes can be combined in an incalculable number of configurations for the creation of structural frameworks and architectural spaces. Combining these many different shapes in so many different ways requires a connection system that is flexible, versatile and yet practical. This is particularly challenging wherein architectural applications entail panels of considerable thickness. It is this issue, that of joining a large number of different shape and size panels of architectural thickness, that is addressed by the second aspect of the invention.

To begin with the first aspect, the system for determining panel shapes derives from a three-dimensional grid based on a single, large "primary" cube comprised of twenty-seven smaller "subcubes." Just as a large square can be divided into many smaller, proportional "sub-squares," for example nine, a large cube can be divided into many smaller "subcubes," which in the case of the present invention is twenty-seven. Common to both a two dimensional square and a three dimensional cube is the fact that the lines which define them are always of equal length and always meet at 90 degrees, making them uniquely symmetrical and interchangeable. In the present invention, the large or "primary" cube is envisioned as a three dimensional grid that reveals the twenty-seven cubes that comprise it. The points where the lines of this grid intersect are called vertices, more commonly thought of as where the corners of cubes or squares meet. To obtain an assortment of panel shapes useful for a building system, lines connecting three and four vertices within the twenty-seven cube grid are drawn in all possible combinations to form two dimensional planes. This process produces an assortment of fifty-nine plane shapes, which include three squares, twenty-one rectangles, twenty-four right triangles, nine isosceles triangles and two irregular triangles. In turn, combining these shapes in all possible ways produces sixty-one three dimensional, simple polygons, which include three cubes, three tetragonal primitives, three orthorhombic primitives, nine isosceles prisms, nine right triangular prisms, eleven trirectangular tetrahedrons and fourteen right square pyramids (eight of which occur in both left and right-handed forms).

This process, that of breaking a simple cube by means of an interior grid into sixty-one polyhedral forms using the integral fifty-nine plane shapes is that which has been termed the

"Fractionalized Cube." It describes the creation of the aforementioned panel shapes and polyhedrons as smaller two and three-dimensional subdivisions or "fractions" of the original cube. Although the fifty-nine plane shapes (hereafter called panels), can be used to construct polyhedrons, fabrication of polyhedral forms is not the primary intent for application of the present invention. Polygons comprised of Fractionalized Cube panels will, similar to other polygons, will have a certain usefulness as single entitles, or more often, in repetitious sequences to form structural frameworks like bridges, towers, space frame platforms, and so on. More importantly, as a result of the variety of their shapes, sizes and proportions, the fifty-nine fractionalized cube panel shapes are intended primarily for architectural applications in the creation of aesthetic, structural and functional architectural spaces.

Two dimensional squares and rectangles along with three dimensional cubes, tetragonal and orthorhombic primitives, which represent the most prevalent forms found in conventional construction and architecture, occur readily within the fractionalized cube grid. They are also the most common and useful for architectural solutions and space planning. They provide floor areas, wall areas and room volumes that are the most efficient and functional for the incorporation of furnishings and arrangements which can accommodate almost limitless occupancy requirements. This contrasts significantly with architectural designs based on polyhedral forms like tetrahedrons, icosahedrons, dodecahedrons, etc., where the predominance of angled surfaces and space inflexibility make functional adaptations, and installation of furnishings difficult and impractical.

An important aspect of the Fractionalized Cube is that being the common denominator for fifty-nine panel shapes constitutes a format, which inventory of shapes can literally serve or function as a design tool. The facility for which these shapes can be manipulated and assembled enables a designer to literally sculpt and create architectural forms using these shapes as a medium. The architectonic discipline inherent in employing such related shapes will result in designs that display a natural logic and consistency in any given assemblage, providing an important, built-in advantage in the development of architectural solutions.

The generation of an inventory of panel shapes as based on the Fractionalized Cube in the present invention is not limited to, or by, this particular grid. It was selected, or preferred, because of the reasonable number of useful panels whose variety of shapes and sizes seemed most appropriate for architectural applications.

Although simple in concept, the generation of an inventory of panel shapes based on such a three dimensional grid for the purpose of architectural design has not heretofore been employed.

A major reason a prefabricated panel construction system with shapes based on a three dimensional grid such as the Fractionalized Cube has not been produced is due to the extraordinary difficulty in creating a node (joint connector located at vertices) capable of accommodating the vast number and combinations of strut angles, or angle of panel corners that must converge at any given vertice. To assemble panels whose shapes are derived from the fractionalized twenty-seven subcube grid, a node at any given vertice would have to be designed to accommodate struts converging at that point from an incalculable number of combinations of

290 strut angles. Also, a panel joinery system would need to be able to accommodate planes converging on axes parallel to struts from any combination 341 dihedral angles. These criteria far exceed the capabilities of conventional strut-node assembly systems. In actuality, any given node would need to be capable of receiving struts from all the vertices of not just one twenty-seven subcube volume, which represents only one quadrant of the node, but eight. In other words, such a node would need to be capable of linking struts between itself and all the vertices defining a much larger cube made up of 216 subcubes in order to be truly functional for application of Fractionalized Cube geometries sought with this invention.

Therefore, in light of this demanding criteria, in addition to those described in Background of the Invention, it is clear that the conventional strut-node structural framing system for carrying panels is not feasible for assembling panels derived from the Fractionalized Cube inventory, as intended. Neither, however, is a mere adaptation and application of hinges, as typically conceived, capable of achieving above described joinery requirements; although the approach to be described in the present invention is more closely associated with the hinge idea.

In order to make possible the joining of the above described plurality of panel shapes and sizes in such a plurality of unpredictable combinations, especially those of architectural thickness, it is important to first understand the fundamental difference between strut-node and hinged approaches and their distinction from the present invention. The familiar strut-node system consists of struts that are directly and symmetrically centered on axes between vertices, anchored at each end by physical connection devices, called nodes, centered on these vertices. The hinge

consists of two planes parallel to the axis between vertices that are joined by means of a solid rod or pin passing through overlapping loop extensions of these two planes called flanges. In construction, it is these flanges that are attached to the panels being joined in an assembly. Typically, however, struts are not joined to each other using hinges. Hinges are primarily for panels. It should also be emphasized that increased panel thickness correspondingly increases the difficulty of employing hinges as a means of panel joinery, greatly limiting versatility.

To make possible the freedom of assembly required for realizing Fractionalized Cube designs, important variations on and modifications to the hinge approach are required. First of all, struts as framing members are paramount, whether they be independent or an integral part of panels. Panels are to be centered within the frames defined by struts; that is, the centerline of panel thickness passes through the centerline of the struts in line with the axis between vertices, versus attached to the top or bottom of struts. This facilitates varying numbers of panel bearing struts to occur adjacent, parallel to and rotational about a given axis. This makes the incorporation of more panels and the means for joining them to each other much simpler than is possible with framing systems that rely on a single strut centered on an axis. In addition, no predesigned physical node is required at the vertices. The node is essentially replaced by a hub, which is a structural assemblage created by connecting the corner elements of panels - of only those panels being joined to each other - in the immediate proximity of the vertices.

In other words, a hundred different panel combinations, with respect to a given vertice, would result in a hundred different hub configurations anchoring panels to each other about that

point, without the need for nodes, custom modifications or design variations of that element. This goes beyond the joinery capabilities at the vertice condition of all other joinery systems, or methods, knowledgeable to Applicant. It is these two important factors: (1) struts that are offset, parallel to and rotational about the axis between vertices and (2) the elimination of a predesigned physical node at the vertices, which completely liberates the format for architectural space-forming by allowing two or more planes of varying shape and size to be joined at theoretically any angle through 359 degrees around any given axis, and any combination of axes 359 degrees about any given vertice from all directions, providing unparalleled versatility for creating architectural assemblages.

To achieve joinery of two or more planes about a common axis at a multitude of angles with respect to each other as described above, a joinery detail is required that is capable of doing what a hinge does, but with greater flexibility, which provides objects and advantages not possible with the common hinge or variations thereof. The mechanism for joining architecturally scaled panels based on the Fractionalized Cube panel inventory requires two distinct but related joinery assemblies. One joinery assembly type is required at the corners of panels or where formed by two struts on the same plane referred to as a first joinery assembly. A second joinery assembly is preferred along the sides of panels. Both joinery assemblies are comprised of only a few simple components, efficient and economical to both produce and assemble.

Common to both joinery assemblies is first, the strut. Struts are structural members which may be independent elements, or incorporated into and define the perimeter of panels whose

loads, in turn, they bear. Said struts are offset from, parallel to and rotational about the axis between any two vertices and panels being joined. A second component is a cylindrical (tubular) element which is centered on the axis between any two vertices and panels being joined and is referred to as the "centerline element". Compared to a common hinge, this element replaces the rod, or pin, use to link together its two flanges. The third component common to both the first and second joinery assemblies is one which forms a bridge between the strut-panels edges and the centerline element. Although similar in their bridging function, the design, orientation and application method of this component is quite different between the first and second joinery assemblies. The first joinery assembly is employed at panel corners. It is designed to join with like assemblies at the corners of other panels meeting at the same vertice to create a structural hub about that, or any, given vertice common to said panels. At the panel corner location, this "bridge" element consists of a structural planer member that is horizontal with and parallel to the axis between vertices, i.e., strut-panel sides, and is referred to as a "web".

In the second joinery assembly, employed along the sides of panels, the bridge element is also a structural planer member. However, here it is anchored perpendicularly with respect to the axis between vertices and strut-panel sides. This is to accommodate and exploit the panel's thickness in order to achieve a structurally stronger tie between panels, and to provide for locking the dihedral angle between panels in order to prevent their rotation about the axis with respect to each other. This bridge element in the second joinery assembly is referred to as a "bracket". In addition to its role in joining panels about a common axis, the bracket affords the additional advantage of providing a means for attaching closure membranes for concealing the joint cavities

and associated components. These "joint closures" are primarily a matter of architectural detail and not part of the invention described herein.

Other differences between the bridging element of the first and second joinery assemblies are that with the first joinery assembly, the "web" is either an integral part of, or anchored permanently to, the panel side on the centerline of its thickness. The "bracket" of the second joinery assembly would be a separate element for adjustable positioning along the panel's side, to which it is then anchored. Fastening these web and bracket bridge elements to the tubular "centerline elements" is accomplished by two different means. With the first joinery assembly, independent elements called "collars" are utilized. These elements are analogous to the barrel loops of the common hinge. With the hinge, these loops are integrally formed as part of, or extension of, the flange. In case of the present invention, however, this loop is a separate, detached element, permitting it to be positioned in various numbers and locations along the web. This eliminates the need for predetermining and prepositioning this particularly important connection element, contrary to as required with the more familiar hinge designs. The loop portion of these collars wrap around the tubular centerline element in a manner similar to a stove clamp. Two flat tabs extending from one side of the collar loop is designed to grip the web element to which it is simply bolted, completing the strut-panel side to centerline element connection.

The bracket of the second joinery assembly, being perpendicular to the axis between vertices, therefore perpendicular to the centerline element, allows this element to be so designed

that it self-wraps around and clamps to the tubular centerline element. The brackets of one panel are then simply abutted and bolted to the brackets of adjoining panels, effecting panel to panel joinery. This bolting together of brackets of adjoining panels also effectively locks the position or angle of the panels with respect to each other. This occurs because, in a plane perpendicular to panel sides, a triangulation of three anchorages, strut-panel side, centerline element and bolts, occurs, preventing rotation, or any movement, of panels with respect to each other. Additional bolts simply reinforce this triangulation to stiffen the joint.

This is not the case, however, at the first joinery assembly where only two anchorages occur, at the strut-panel side and centerline element. This is not important, however, where resistance to this rotation is already accounted for with the second joinery assembly brackets, and because this joinery method is only to be used at the vertice condition, where rotation is automatically resisted through triangulation formed by adjoining panels.

Further objects and advantages of the first and second joinery assemblies result from the utilization of open-ended cylinders on axes centerlines, the elimination of the physical node (obstruction), at the vertices, and sequence of elements between adjoining strut-panel sides which create a space between the sides of adjoining panels. Together, these features provide an ideal location for the placement of electrical wiring, junction and outlet boxes, TV, telephone and computer cables, interior plumbing and vacuum lines, vents, and so on. These features would provide great economy in construction, as these so-formed joint cavities naturally provide frequent and continuous chases throughout any given structure. This makes it possible to easily

install utilities and service lines after the prefabricated panels for a building structure are assembled. This means wall, roof and floor panels can be prefabricated on an assembly line without the complications of anticipating and prepositioning these utilities in the panels in the factory, or cutting and placing them into the panels on the building site; both standard and costly procedures in building practice today. Service lines and utilities so installed in joint cavities would then be enclosed and concealed by means of the joint closures referred to above.

Another important advantage and objective of the first and second joinery assemblies is also made possible by the tubular centerline element. This key component of the joinery assembly provides for easy transition to other construction systems such as the more typical hub-strut space frame systems or conventional construction. The basic simplicity in attaching joint components - collars to webs and brackets to each other - results in structures that are easy to both assemble and disassemble. This means that architecture employing Fractionalized Cube panels can easily be altered, reconfigured, added to or subtracted from with virtually equal facility. This contrasts dramatically with conventional construction, where building revisions entail painstaking and time-consuming destruction and reconstruction.

An additional related advantage and objective of this invention comes as a result of being a modular panel system with inherent prefabrication accuracies, along with panels whose integral and separate joinery components are self-aligning. In practice, these features dispense with the frequent measuring, cutting and fitting, etc., typical in conventional construction. Design changes, either during the drawing phase or on the site, would easily be accomplished through

substitution of panels whose field installation would be facilitated by their independence from utilities and use of simple connection components and methods.

The above outlines the primary embodiments, objects and advantages of the invention - the Fractionalized Cube Modular Construction System, which is further described in the figures and drawings of the Brief and Detailed Descriptions of the Invention.

Brief Description of The Drawing

FIGS. 1A - 7E, show the derivation of a modular construction format, consisting of an inventory of panel shapes based on a subdivided cube grid, labeled the Fractionalized Cube. The complexities posed by this format, particularly relating to the issue of joinery are illustrated in FIGS. 8 and 9. A conceptual framework for solving the issue of joinery is shown in FIGS. 10A - 10E and 11A - 11D. This is followed by FIGS. 12 - 23, which illustrate the design approach for two types of joinery assemblies that accomplish the means for mechanically fastening building panels to each other in a manner that solves the criteria of versatility and complexity posed in FIGS. 8 and 9. FIGS. 24A - 24B demonstrate research actually employing one of the joint assembly designs, and FIGS. 25, 26 and 27 illustrate an architectural design based on the present invention, to illustrate the capabilities for producing architecture using the Fractionalized Cube Modular Construction System.

FIG. 1A shows a square.

FIG. 1B shows a square divided into 9 sub-squares.

FIG. 1C illustrates a cube with implied subdivision into 27 subcubes.

FIG. 2A - 2E shows an inventory of 59 panel shapes.

FIG. 3 shows 10 simple polygons based on square and rectangular planes drawn on the Fractionalized Cube grid.

FIG. 4 shows 18 polygonal prisms defined within the Fractionalized Cube grid.

FIG. 5 shows 22 right square pyramid polygons defined within the Fractionalized Cube grid.

FIG. 6 shows 11 trirectangular tetrahedron polygons defined within the Fractionalized Cube grid.

FIG. 7A - 7E represent research studies in space forming and structure based on the panel inventory shown in FIGS. 2A - 2E.

FIG. 8 shows a diagram illustrating how panels are rotational about axes between vertices.

FIG. 9 shows a schematic illustrating radians converging at a vertice common to all eight primary cubes.

FIG. 10A - 10B illustrates a typical prior art approach to space framing, where connecting nodes are centered on vertices and struts are centered on the axes between vertices.

FIG. 10C - 10D shows prior art options for attaching panels to struts.

FIG. 10E shows, with prior art, how only a limited number of struts can be attached to a node at the vertice condition.

FIG. 11A - 11B illustrates two fundamental features of the invention; the offsetting of struts from the axes and the absence of a node at the vertice.

FIG. 11C shows, in the present invention, attachment of panels to struts which allows for more struts and panels to be positioned in more dihedral combinations than is possible in prior art systems as shown in FIGS. 10C – 10D.

FIG. 11D shows, in the present invention, how corners of panel-strut assemblies do not meet at or occupy the vertice location.

FIG. 12 schematically illustrates three basic elements common to first and second joinery assemblies.

FIG. 13 schematically illustrates two additional elements which, when added to the basic components of FIG. 12, comprise the first joinery assembly.

FIG. 14 shows how the components of the first joinery assembly are assembled.

FIG. 15 schematically illustrates the elements which comprise the second joinery assembly.

FIG. 16 shows how the components of the second joinery assembly are assembled.

FIG. 17 shows the basic elements of an architectural panel for application of the Fractionalized Cube modular construction system.

FIG. 18 illustrates typical joining of two panels per FIG. 17, employing the first and second joinery assemblies.

FIG. 19 illustrates the joining of 5 panels, with respect to a common vertice, employing the first joinery assembly elements.

FIG. 20 shows how the first joinery assembly can join and alternate with the typical strut-node framing system.

FIG. 21 shows how thefirst joinery assembly may be anchored to conventional construction.

FIG. 22 schematically illustrates an assembly of the principal and accessory components of the first joinery assembly, as may be employed in actual construction.

FIG. 23 schematically illustrates an assembly of the principal and accessory components of the second joinery assembly, as may be employed in actual construction.

FIG. 24A - 24B shows two views of an abstract structure built to research the feasibility of the Fractionalized Cube modular construction system, using the first joinery assembly method.

FIG. 25 shows a first floor plan design for a residence based on the Fractionalized Cube modular construction system of the present invention.

FIG. 26 shows the first floor plan of FIG. 25 laid out in terms of planes derived from the 59 panel inventory shown in FIGS. 2A - 2E.

FIG. 27 shows a perspective view of a house design, with floor plans shown in FIGS. 25 and 26.

Detailed Description of the Invention

FIG. 1A shows a square 10 with four equal sides 12 drawn with four equal length lines.

FIG. 1B shows primary square 20 comprised of the square 10 of FIG. 1A, whose sides 12 are divided into three equal lengths, which, when connected at right angles, divide square 20 into nine equal subsquares 14. Lines forming square sides 12 and lines 16 delineating the subsquares 14, intersect at points called "vertices" 18.

FIG. 1C illustrates the subdivided square 20, FIG. 1B, extended into three dimensions to create a cube 22, comprising lines 12 and 16, connecting all the vertices 18, of the nine subsquares 14, FIG. 1B, at right angles across the six faces of the subdivided square 20, creating twenty-seven subcubes 24. The lines 16, defining these subcubes 24, and points at which these lines intersect, called vertices 18, constitutes a three dimensional grid which provides the basic format of the Fractionalized Cube, fundamental to the present invention. In this view, most interior grid lines are omitted for clarity.

FIGS. 2A - 2E shows an inventory of fifty-nine panel shapes derived from the three dimensional grid subdividing cube 22, FIG. 1C, by connecting, in two dimensions, all the vertices 18 of subcubes 24, in all possible combinations. These panel shapes, when combined in all possible ways, define sixty-one three dimensional simple polygons, illustrated in FIGS. 3, 4, 5 and 6.

FIG. 2A shows three squares 26 and three rectangles 28 that can be used to make simple orthorhombic, tetragonal primitive and cube polygons.

FIG. 2B shows six right triangles 30 that comprise the sides of right triangular prisms and the perpendicular sides of right square pyramids and trirectangular tetrahedrons.

FIG. 2C shows eighteen rectangles 32 which comprise the hypotenuse planes on isosceles and right triangular pyramids.

FIG. 2D shows eighteen right triangles 34 which make up the diagonal faces of right square pyramids.

FIG. 2E shows eleven isosceles 36, and irregular 38, triangles which make up the diagonal faces of trirectangular tetrahedrons.

FIG. 3 shows how three cubes 40, three tetragonal primitives 42 and four orthorhombic primitives 44 (regular polygons) can be composed from different combinations of subcubes 24 by

connecting squares 26 and rectangles 28 from the fifty-nine panel inventory, defined within the Fractionalized Cube grid 22 of FIG. 1C.

FIG. 4 shows how nine isosceles 46 and nine right triangular 48 prisms can be formed within this cube grid 22, using squares 26, rectangles 28, 32 and right triangles 30.

FIG. 5 shows fourteen right square pyramids, eight of which occur in both left-hand and right-hand conditions, using squares 26, rectangles 28, and right triangles 30 and 34.

FIG. 6 shows ten trirectangular tetrahedrons, one of which occur in both left-hand and right-hand conditions, comprised of three right triangles 30 whose faces are made up of nine isosceles 34 and two irregular 36 triangles. Eight of these forms can be described three ways which can be visualized by rotating each of the three axes x-y-z to the vertical position.

FIG. 7A - 7E represent five abstract studies with architectural implications, constructed as part of the research into the space forming capabilities of the fifty-nine panel shapes, FIG. 2A - 2E, derived from Fractionalized Cube geometry. FIG. 7E is a composite of FIG. 7A and FIG. 7B with added trestle 49 joining the two.

FIG. 8 illustrates the first of two major conditions that need to be addressed if structures are to be assembled with the complexity and versatility demonstrated in FIGS. 7A - 7E. This will require that a panel 60, represented here by planes 56, or multiple of panels 60, be capable of being positioned at virtually any angle through 360 degrees about any axis 52 between vertices 18 and dihedral angle 54, with respect to each other. Here, two planes 56 are shown as rotational

about two of only five axes 52, representing the 145 axes actually required for application of the Fractionalized Cube modular construction system.

FIG. 9 shows a cluster of eight cubes, each representing a primary cube 22 comprised of twenty-seven subcubes 24 of FIG. 1C. The node 64, located at the central vertice 18 of the cluster, shows radians 62, representing strut angles converging from only twenty-four vertices on a single cube to this centermost vertice 18 (node 64) location. These radians represent only a fraction of the 290-strut angles from the vertice 18 intersections of 216-subcubes 24 of all eight primary cubes 22. This dramatizes the second, most challenging, condition to be addressed by a modular construction system required for the intended application of the Fractionalized Cube panel inventory as illustrated in FIGS. 7A - 7E.

FIG. 10A schematically illustrates prior art, conventional strut-node, approach to structural and space forming assemblies. Here, a physical node connector 64 is centered on vertices 18 with individual struts 66, centered on the axis 52 between nodes 64 as illustrated in FIG. 10B. These strut configurations thus define areas 58 for panel 60 infill.

FIGS. 10C is prior art showing how panels 60, centered on struts 66, may be attached, similarly, as shown in FIG. 10D, to the top of struts. These illustrate the limited assembly options and number of panels capable of being attached to any given strut 66.

FIG. 10E is a prior art schematic view of FIG. 10A, joinery condition at vertice 18, illustrating the problem of anchoring more than just a few struts to any given node-connector 64,

located on said vertice. The more struts, the more massive and complicated the node 64 must be. Space 58 between struts 66 may be infilled to form panels 60, or panels 60 may lay on top of struts 66, per FIG. 10D.

FIG. 11A schematically illustrates the structural essence of the present invention in contrast to the strut-node framing system FIG. 10A - 10E. This approach literally turns inside out the strut-node system FIG. 10A - 10E. Here, instead of struts 66 and node 64 centered on their respective axes and vertices, struts 66 are offset 67, parallel to and rotational about the axis 52 between vertices 18 as shown in FIG. 11A - 11B. Also, the physical connecting node 64 as shown in FIG. 10A - 10E, centered on vertices 18, is eliminated as shown in FIG. 11A - 11D. This space, around vertice locations and around axes between vertices so vacated, makes it possible to position varying numbers of panels 60 in varying combinations about said axes 52 between any two given vertices and about the vertices 18 themselves as shown in FIG. 11D. This freedom to position panels in such a variety of locations with respect to each other about their common axis as shown in FIG. 11C , and vertice as shown in FIG. 11D, is the most essential requisite for a truly comprehensive modular system for prefabricated panel assemblies with sought-after capabilities illustrated in FIGS. 7A - 7E.

To this point it is seen that an inventory of 59 panel shapes FIG. 2A - 2E has been established, based on a 27 subcube grid termed Fractionalized Cube, which can be assembled in multitude of ways to create a great variety of structural shapes and space enclosures. It is also seen that to combine panels with the degree of flexibility illustrated in FIG. 7A - 7E creates

immense complications due to the large variety of joinery conditions required to accommodate so many angles of struts and panels about common axes and vertices as defined in FIGS. 8 and 9. It is shown in FIG. 7A - 7E that this is easily accomplished where planes of very little thickness are used. The Fractionalized Cube concept would be little more than a curiosity of no practical use if planes, thickened for architectural applications, could not be joined with the same versatility. The first step in achieving this capability requires, as discussed, removing the struts 66 from axes 52 and the physical node 64 from vertices 18, as illustrated - FIG. 11A - 11D. This provides many more options for panel-strut combinations about axes and vertices, as compared with the conventional strut-node system. The issue then becomes the nature of the actual physical connection of panels to each other about any given axis or vertice and across the gap between struts or panel sides, as presented in FIGS. 11A - 11D, which essential objective of the invention is described in the drawing proceeding.

FIG. 12 schematically illustrates three basic components common to the two joinery assemblies embodied in the present invention, and referred to as the first joinery assembly and the second joinery assembly. These fundamental elements include the panel 60, the strut 66 which carries the panel, and the centerline element 68, an open-ended cylinder or segment of tubing.

FIG. 13 shows an exploded view of the basic elements of the first joinery assembly which shows, in addition to the panel 60, strut 66 and centerline element 68 of FIG. 12, a "bridge" element - a horizontal planer member, parallel to the panel 60 and strut 66, called a "web" 70, and an independent tubular ring, or barrel loop, with tab extensions called a "collar" 50.

FIG. 14 illustrates how the components of the first joinery assembly shown in FIG. 13 are put together. The web 70, anchored at and parallel to the centerline of the strut 66 (indicated with a slot as shown in FIG. 13) bridges the space between the strut-panel side 66 and the centerline element- tubular segment 68 centered on axes 52 between vertices 18. The barrel of collar 74 wraps around the centerline element 68, from which collar rectangular tabs extend above and below the web 70, to which it is bolted 88, effectively clamping the centerline element 68 to the web 70, which in turn is anchored to the strut 66, carrying panel 60, completing the linkage.

FIG. 15 shows an exploded view of the basic elements of the second joinery assembly, which in addition to the panel 60, strut 66 and centerline element 68 of FIG. 12, shows a structural planer member that is also a "bridge" element, positioned perpendicular to the panel 60, strut 66 and centerline element 68, called a "bracket" 72.

FIG. 16 illustrates how the components, or elements, of the second joinery assembly shown in FIG. 15 are put together. The bracket 72, anchored perpendicular to the strut 66 and axis 52, carrying panel 60, bridges the space between the strut 66 and tubular segment-centerline element 68 centered on axis 52 between vertices 18.

FIG. 17 illustrates the basic elements of a typical architectural panel for application of the Fractionalized Cube Modular Construction System. This consists of area 58, which may be left open or filled with a variety of architectural materials and treatments forming a panel 60, struts 66, three or four of which would define the perimeter and form the panel's sides, webs 70, a first

joinery assembly element located at panel corners, brackets 72, and a second joinery assembly element located intermediately and intermittently along the panel-strut sides 66. Webs 70 are fixed at their corner panel-strut locations, whereas brackets 72 are laterally adjustable along the panel-strut 66 sides. Lines 76, coincident with the axis (axes) 52, officially define and illustrate the panel's actual perimeter that would be drawn from panel inventory in FIG. 2A - 2E.

FIG. 18 illustrates the joining of two typical FIG. 17 panels, incorporating all the elements of the first and second joinery assemblies with respect to axes 52 (coincident with actual panel perimeters 76). In addition to elements 60, 70 and 72 as described in FIG. 17, tubular segment-centerline elements 68 are shown centered on the axis 52, linking brackets 72 to struts 66, and webs 70 to each other in relation to vertices 18, by means of collars 74.

FIG. 19 illustrates in greater detail the function of the first joinery assembly, critical to the application of the invention, which is the formation of a structural hub 78 that surrounds vertice 18, common to strut-panel assemblies being joined, as opposed to and replacing the physical node connector 64, centered on a given vertice 18. This feature provides for the joining of strut-panel corners in the multitude of combinations and directions, as prescribed in FIG. 9, with the versatility required to achieve architectural constructions of the complexity illustrated in the studies of FIG. 7A - 7E. This FIG. shows hub 78 as a structural assemblage that consists of the first joinery assembly elements at the corners of five panels, anchored to each other as described in FIG. 14, about a common vertice. In addition to providing anchorage for strut-panel corners, the elimination of a physical node obstruction allows for continuity of the utility chase feature

throughout the joints of Fractionalized Cube panel assemblages. In this view, panels 60 are omitted.

FIG. 20 illustrates a further object and advantage of the invention as a feature of the first joinery assembly, FIG. 15, because of its ability and facility for joining, or alternating, with the more typical strut-node space framing and related systems as shown in FIGS. 10A - 10E. Here, a physical node 64 is positioned at the vertice 18 from which truncated struts 66, or dowels 80, extend to pass through the tubular centerline element 68, which in turn is attached to the webs 70 of a Fractionalized Cube panel by means of collars 74. In this case, the centerline elements 68 act as sleeves, providing a simple means for anchoring struts 66 from a conventional strut-node frame.

FIG. 21 shows how, similarly, the first joinery assembly components facilitate joinery with conventional construction. In this case, the centerline elements 68, acting as sleeves, receive dowels 80 that are anchored to a steel plate 82 which in turn is fastened to concrete 84 with anchor bolts 86. This represents just one of many options for connections with conventional construction materials possible with the joinery systems of the present invention.

FIG. 22 shows a schematic architectural detail illustrating the joining of two panels using the components of the first joinery assembly and how such a joint might appear in actual construction. The primary elements, consisting of panels 60, struts 66, webs 70, centerline element 68 and collars 74, are joined about a common axis 52. Other elements, such as joint closures 90 concealing the joint mechanism and utilities cavity, are indicated as well as related

components, such as bracing 92 and attachment hardware 88, representing thru-bolts, screws or other fasteners as required.

FIG. 23 shows a schematic architectural detail illustrating how the components of the second joinery assembly might appear in actual construction. Assembled in accordance with FIG. 16, the drawing shows, in addition to the principal elements of panel 60, struts 66, brackets 72 which bridge between struts 66 and the centerline element 68, various supplemental or accessory components required to complete a joint assembly. These include joint closures 90, brace elements 92, and fastening elements 88, as required. It can be seen how fastening elements 88, which bolt the two brackets to each other around the centerline element 68, prevents movement or rotation of the struts and corresponding panels with respect to each other, effectively fixing the dihedral angle between panels.

FIG. 24A shows one view of an abstract structure built as part of the research into the construction feasibility of utilizing Fractionalized Cube panels and joinery methods in accordance with criteria sought in the present invention. The structure is comprised of 49 panels derived form the inventory of panel shapes FIG. 2A - 2E, selected as representative of the total range of panel shapes and sizes, from largest to smallest, and incorporating the severest angles. This structure, based on a 48x48x48 primary cube, utilizes the first joinery assembly exclusively, which components include struts 66 which define panel shapes 58, tubular centerline elements 68, collars 74 and webs 70 which bridge between the struts 66 and centerline tubular segments 68. The panel-shape open space 58 is the area defined by the struts that may be infilled with a wide variety

of materials to form solid panels 60. Hub configurations 78, formed with the first joinery assembly elements, are evident about all 30-vertices incorporated in the structure. The opposite side of this same structure FIG. 24B further illustrates the versatility with which forms can be generated employing Fractionalized Cube geometry and joinery methods.

FIG. 25 shows the first floor plan of a residence designed to illustrate the primary objective and advantage of the present invention, the Fractionalized Cube Modular Construction System. It illustrates the capability of creating structures which embody practical, structural, functional and aesthetic characteristics and qualities required in architectural applications. This design successfully realized specific program requirements and objectives based entirely on the inventory of panel shapes FIG. 2A - 2E derived from the Fractionalized Cube shown in FIG. 1C.

FIG. 26 shows the first floor plan of the residence described in FIG. 25, laid out in the form of planes 56, selected from the 59 panel inventory of FIG. 2A - 2E.

FIG. 27 shows a perspective view of building design, which plans are described in FIG. 25 and FIG. 26. Features to be noted are solid and glazed, wall and roof panels 60, handrails 94, entrance canopy 96, angle bay window feature 98, in addition to the incorporation of decks 100 and planters 102, all of which illustrate the capabilities and design potential in the Fractionalized Cube Modular Construction System of the present invention.